ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

3D Structuration of LTCC / Thick-Film Sensors and Fluidic Devices

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Outline

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1. Introduction - 3D structuration & techniques
2. Glass sealing - thick-film microfluidics
3. Directly cutting LTCC - "large-channel" microfluidics
4. Carbon-based sacrificial layers - processing & features
5. Mineral sacrificial layers - first experiments
6. Conclusions & outlook

1. Applications

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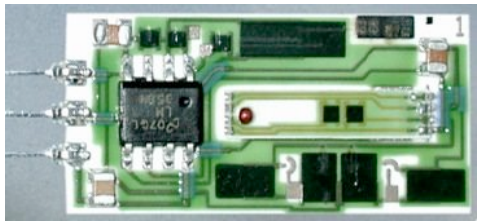
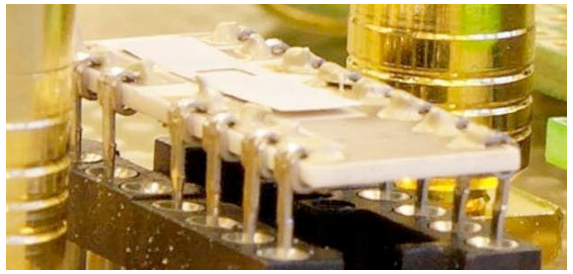
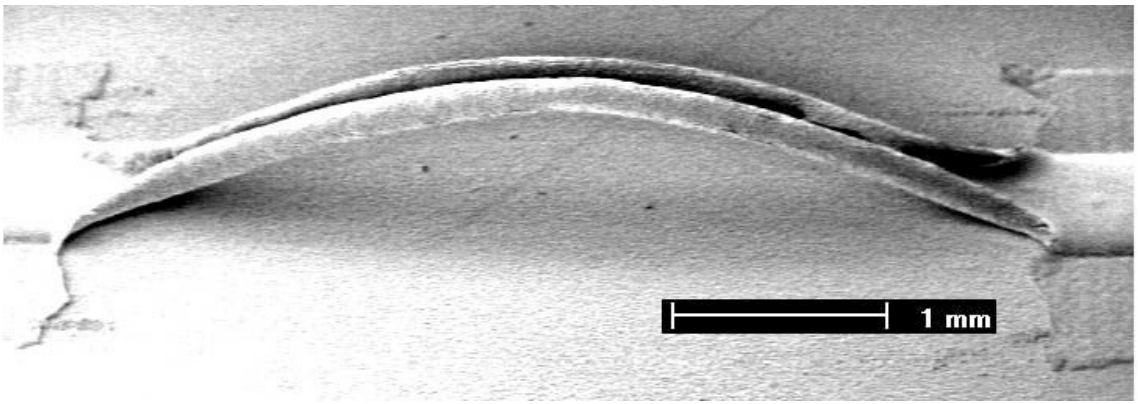
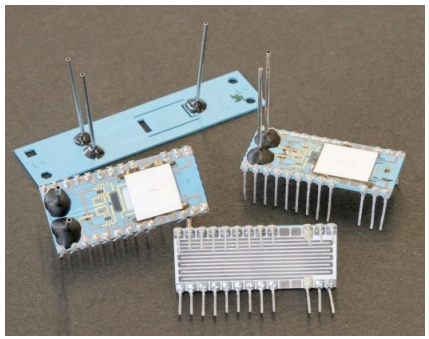
- **Sensors**
  - Micro-force sensor
  - Suspended thermistor

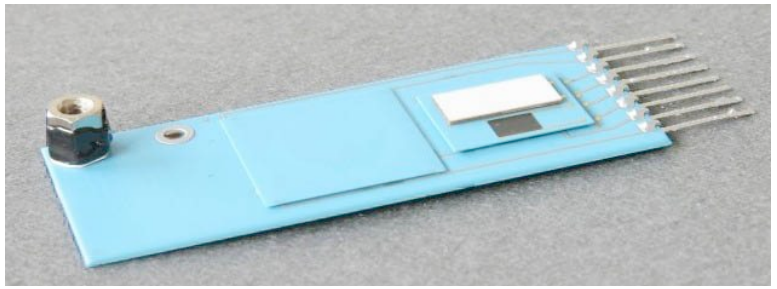






- **Fluidics**
  - Chemical reactor
  - Gas viscosity sensor





1. Structuration methods

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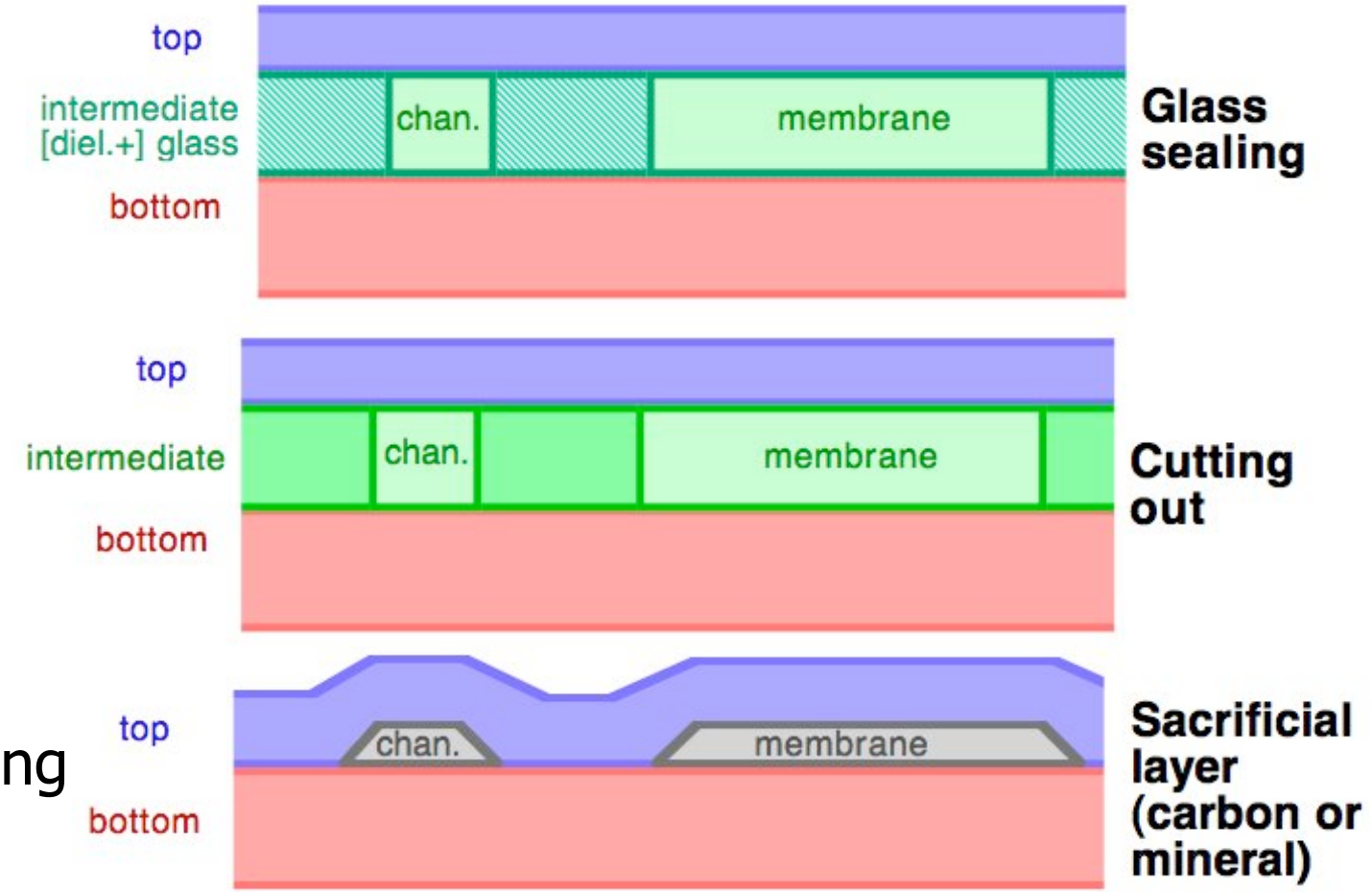
Features

- Vias
- Channels
- Membranes
- Beams

Three types

1) Glass sealing
2) Cutting & stacking
3) Sacrificial layer



1. LTCC vs. alumina for sensors

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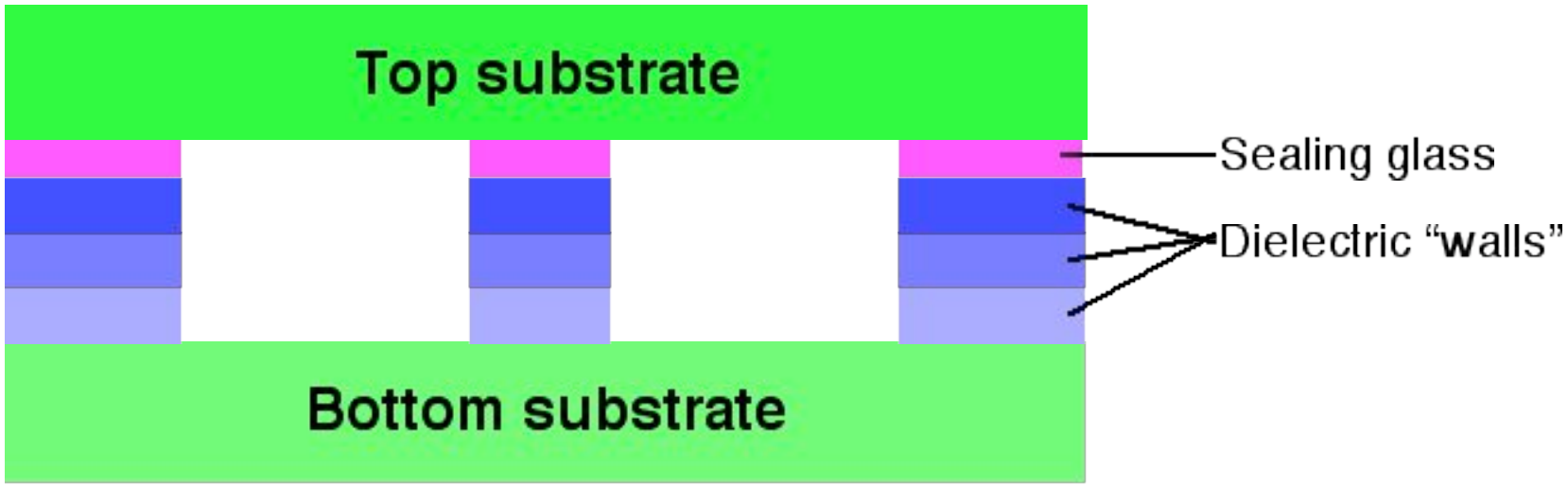
Material	LTCC (DP 951)	Al_2O_3 (96%)	Ratio
Minimal thickness [mm]	0.04	0.17	*0.24*
Short-term strength [MPa]	320	600	*0.53*
10 year strength [MPa]	110	270	*0.41*
Young's modulus [GPa]	110	320	*0.34*
Thermal conductivity [W/m]	3	25	*0.12*
Design strain [ppm]	1'000	800	*1.25*
Flexural sensitivity [kN^{-1}]	5.68	0.11	*53*
Thermal resistance [K/W]	8'333	235	*35*

> LTCC for Thermal, low-range mechanical sensors

2. Thick-film fluidics: glass sealing



- Alumina bottom substrate
- Walls built-up by thick-film dielectric
- Final layer = sealing glass
- Glass sealing of top substrate
- Max practical height: ca. 100 µm
- Simple circuits (1 layer)

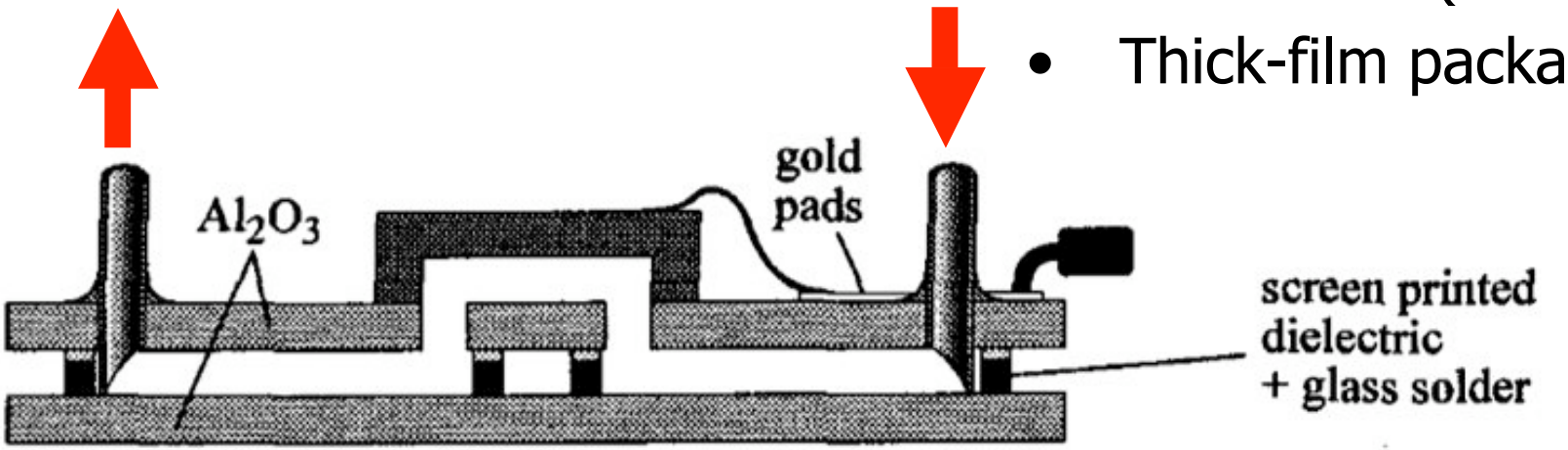
2. MEMS microreactor

(Ch. Alépée - LMIS, 2000)

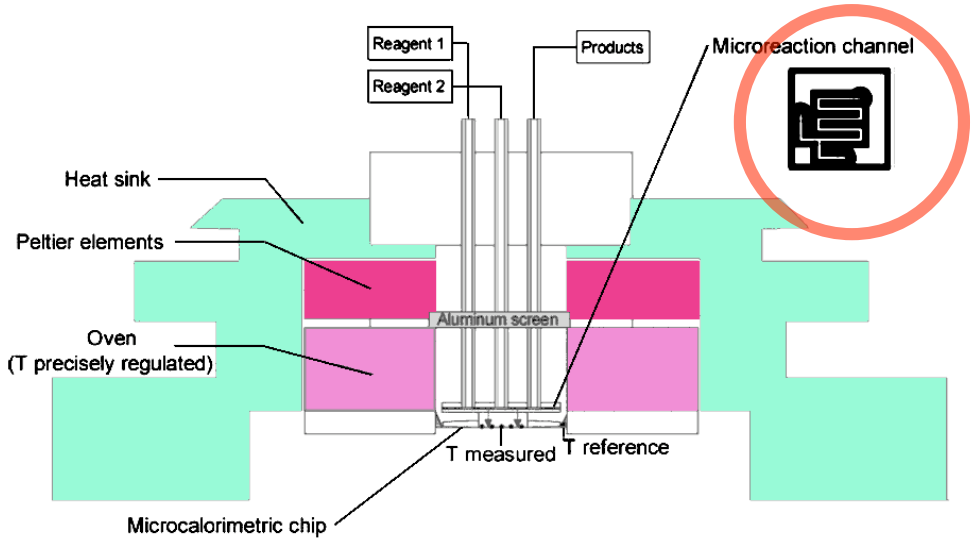
$$CH_3OH \rightarrow CH_2O + H_2$$

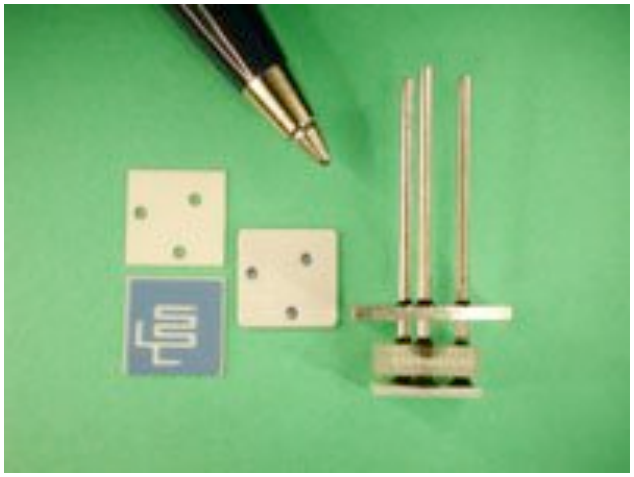
[Na, 800°C]

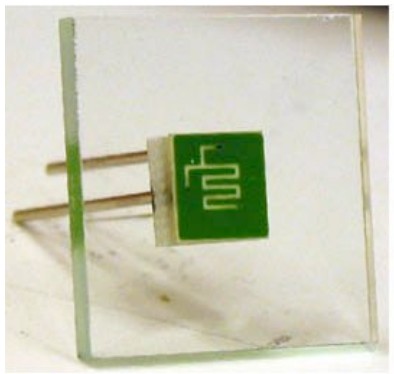
- MEMS microreactor for methanol dehydrogenation into formaldehyde
- Reaction catalysed by Na around **800°C**!
- Inlets / outlets must be at ca. **300°C** (Na vapour)!
- Thick-film packaging



2. Microreactor-calorimeter







(M.-A. Schneider - 2004)

- MEMS microcalorimeter
- Thick-film glass-sealed microreactor
- Alumina…
- …or glass

2. Glass sealing - conclusions

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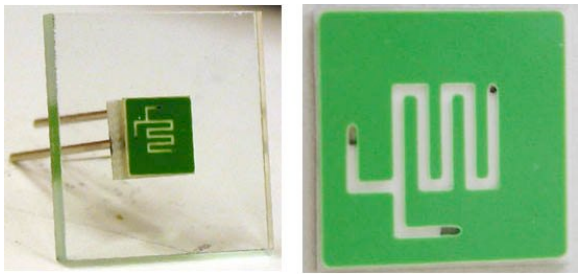
+ Proven technique
+ Straightforward processing
+ Very flexible: ceramic, Si, glass, …

– Tedious if high channels needed
– Practically limited to 1 fluidic layer
– Lower chemical & thermal stability
– Often lead-bearing glasses for low processing temperatures

→ Assembly & sealing of MEMS
→ Transparent modules - glass



3. Cutting & stacking LTCC

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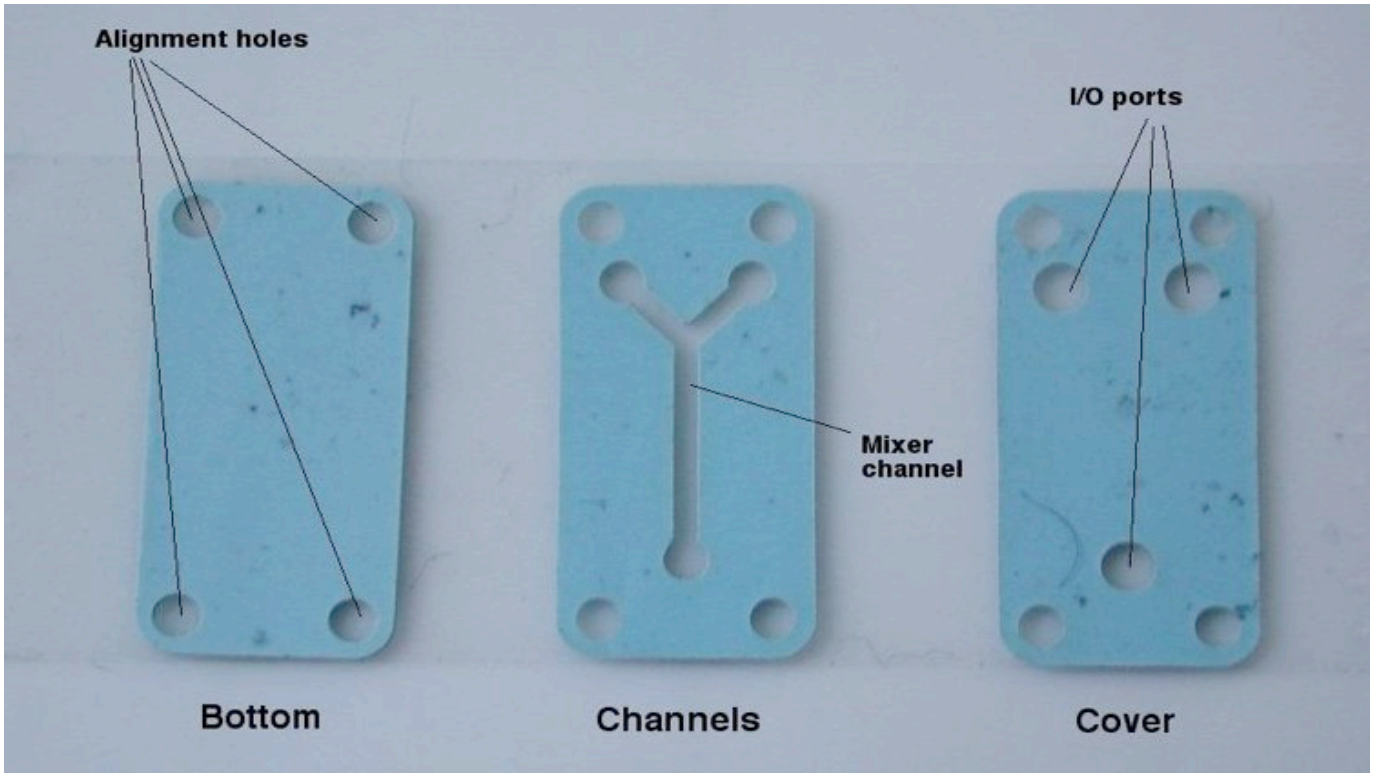
Process

1. Cutting
2. Stacking & laminating
3. Firing



A simple LTCC micromixer

3. Meanders & complex circuits

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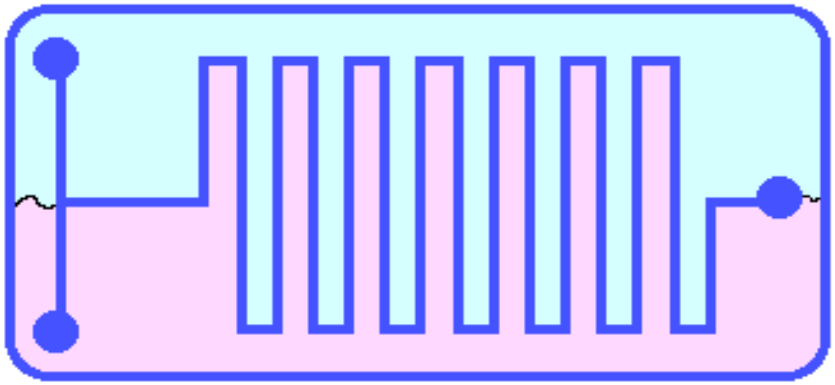
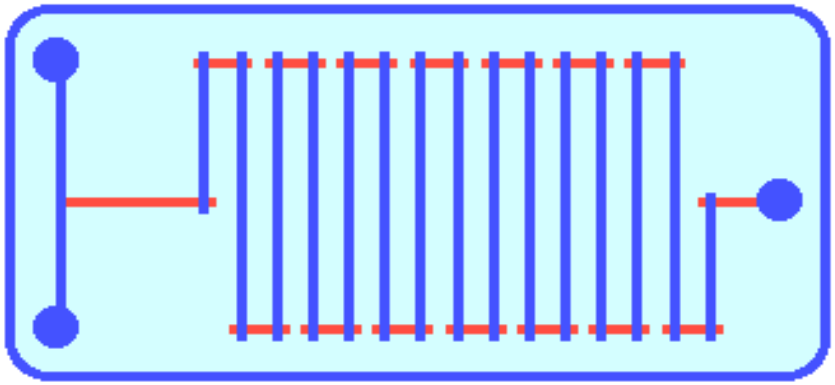
Fabrication of complex LTCC fluidics



- LTCC sheet weak
- Strong risk of clogging



- LTCC sheet stronger
- Less risk of clogging

Sheet 1 (top)
Sheet 2 (bottom)

⇒ Avoid long, narrow & windy cuts!

3. Meanders: zig-zag micromixer

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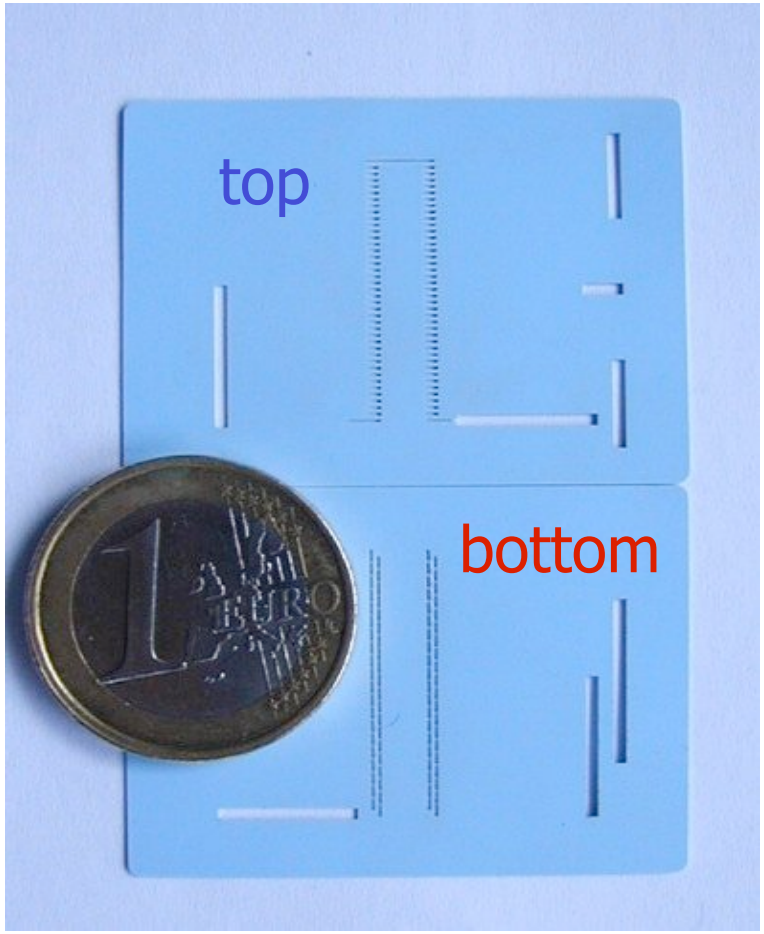
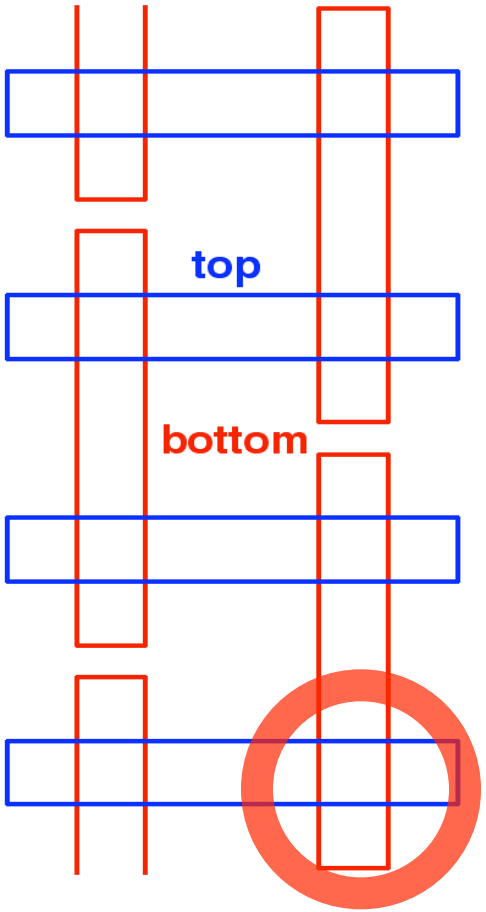
V. Mengeaud, EPFL 2002





- Two-layer "zig-zag" mixer
- Preserves integrity of LTCC layers
- Extra length: alignment tolerances

3. Meanders: zig-zag micromixer 2

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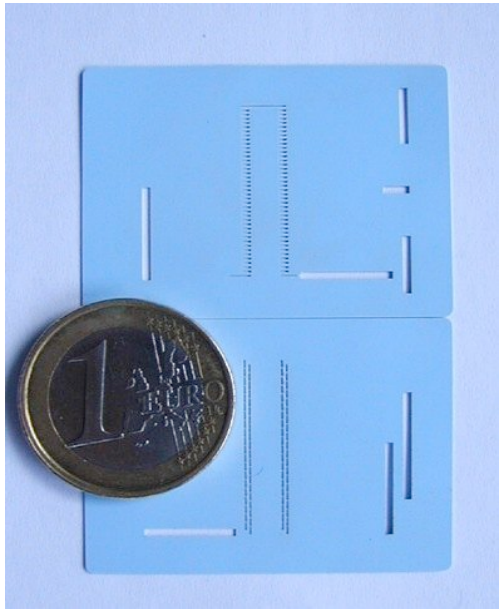
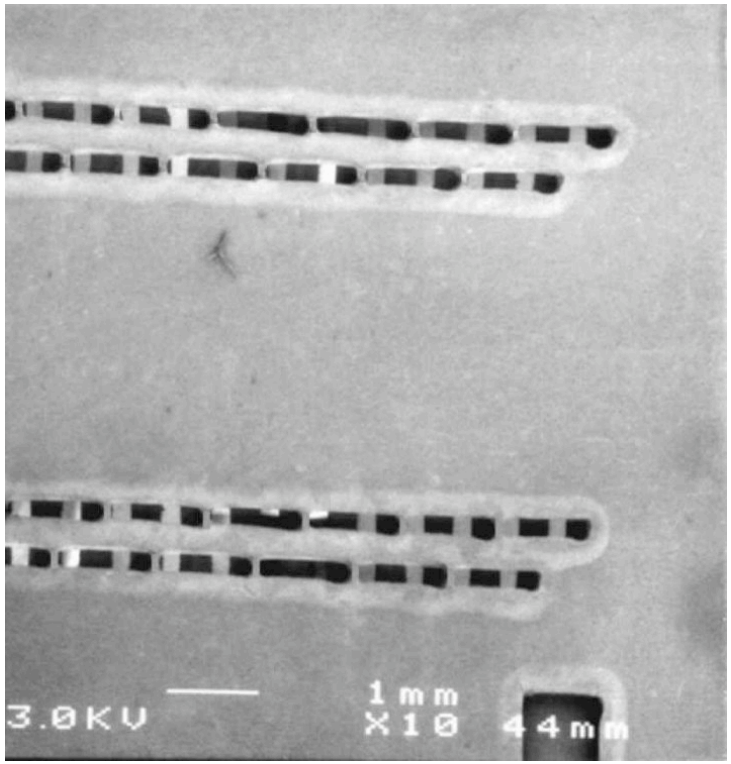
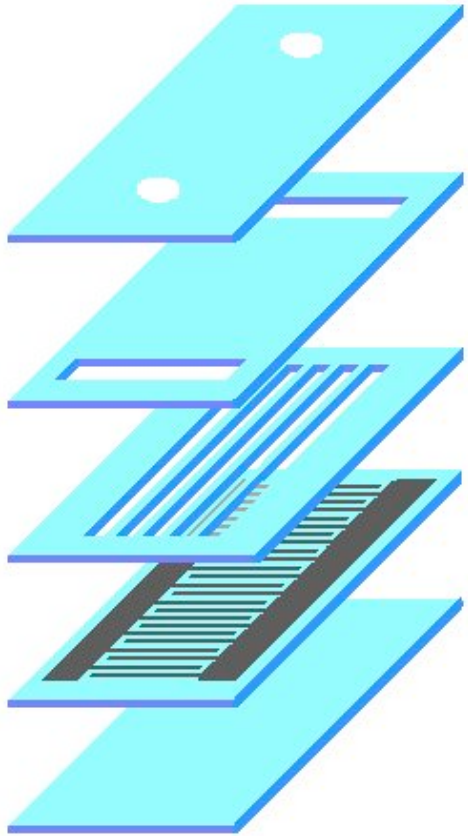
V. Mengeaud, EPFL 2002

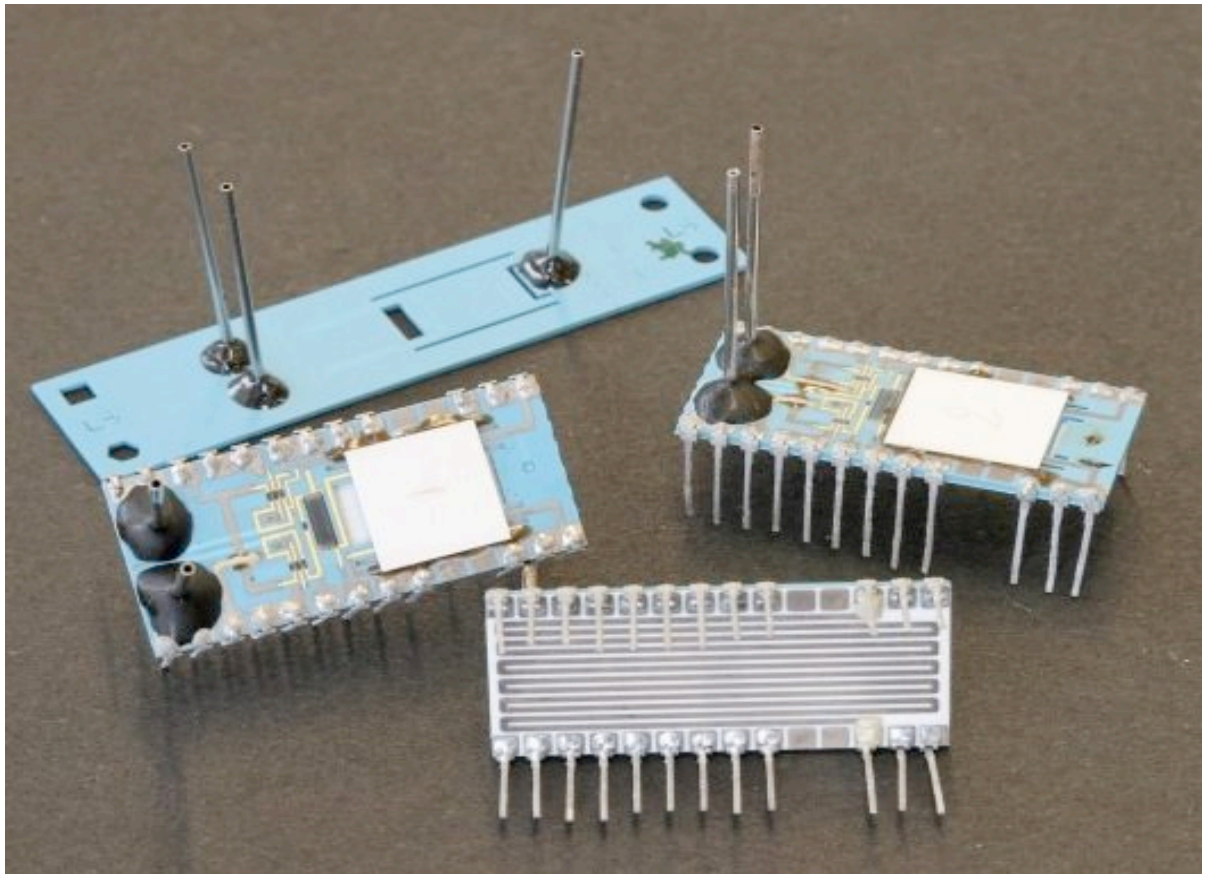






- Reliable structure, no clogging
- + electrodes: electrochemical microreactor

3. Meanders: microcalorimeter

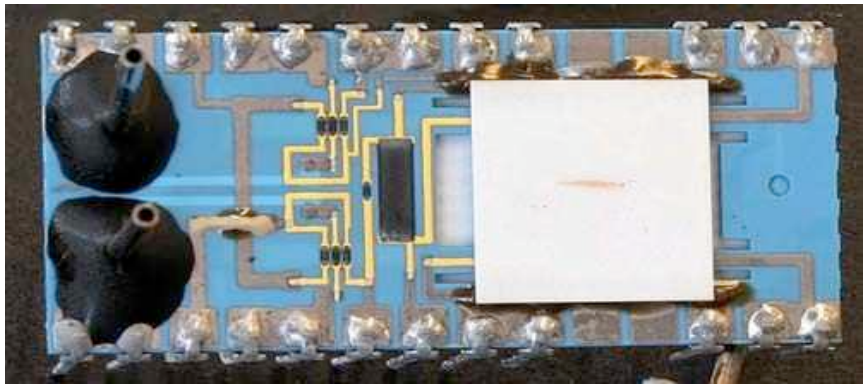


Features:

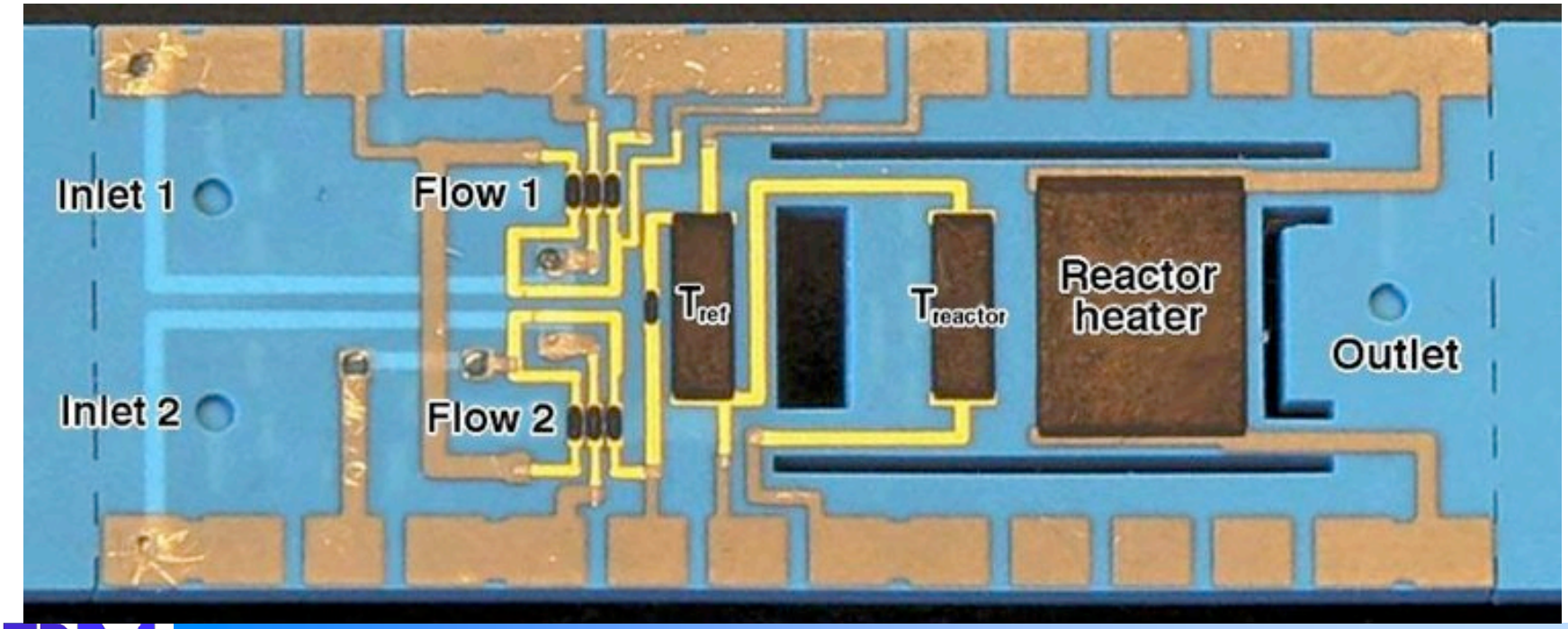
- DIL-24 package
- Global heating track
- Inlet pre-heating zones (meanders)
- Thermally insulated reaction zone
- Microcalorimeter with calibration heater
- Separate flow sensor for each inlet

Willigens, 2005

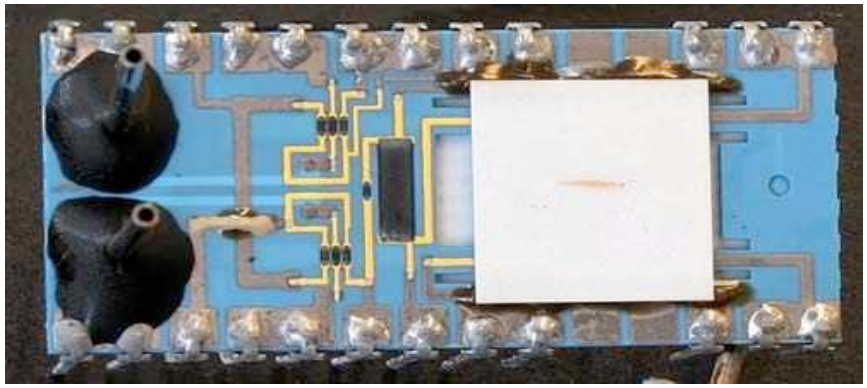
3. Meanders: microcalorimeter 2



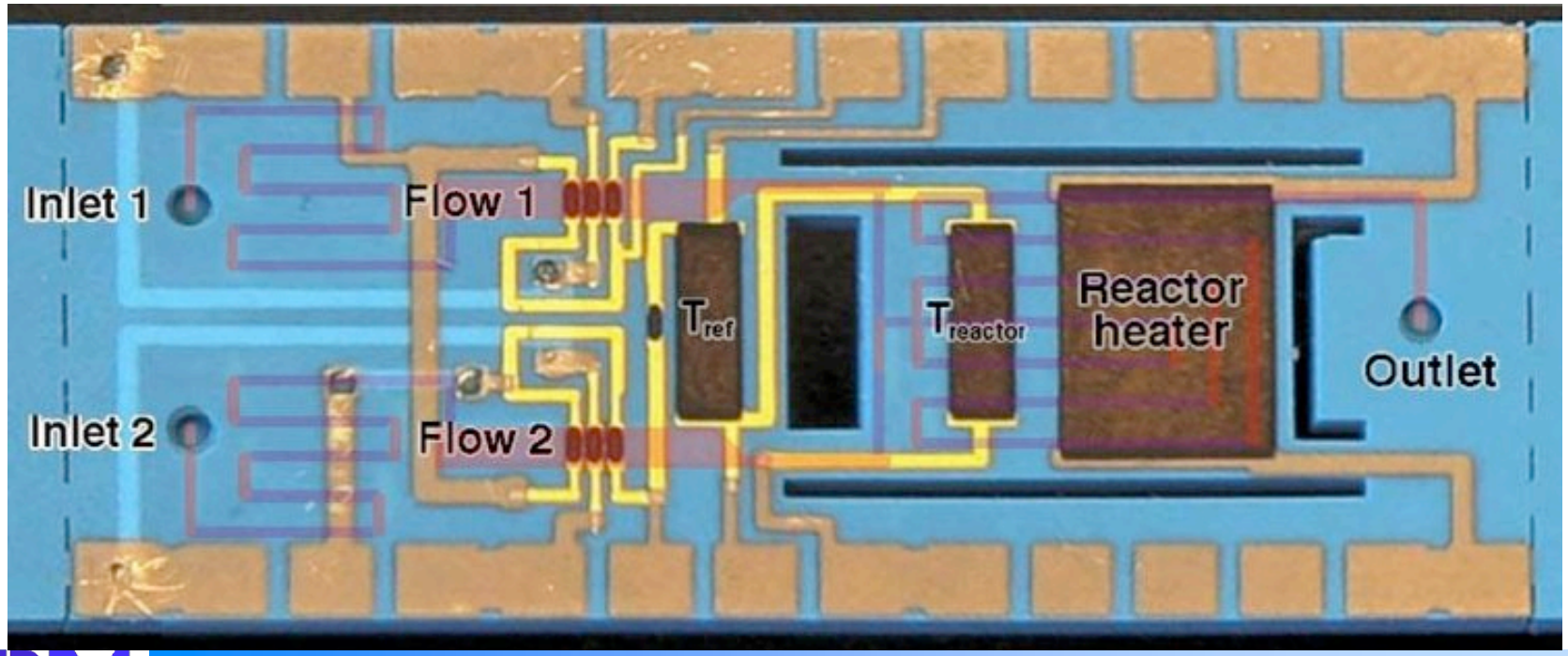
- Complete reactor
- LTCC: elements



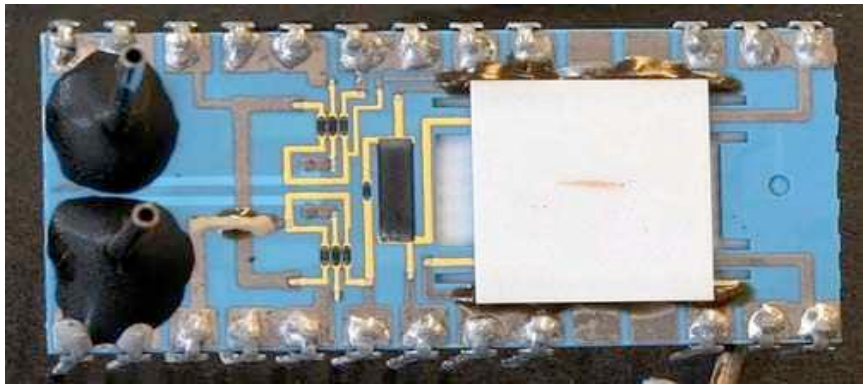
3. Meanders: microcalorimeter 3



- Complete reactor
- LTCC: elements
- **LTCC: fluidic layout**

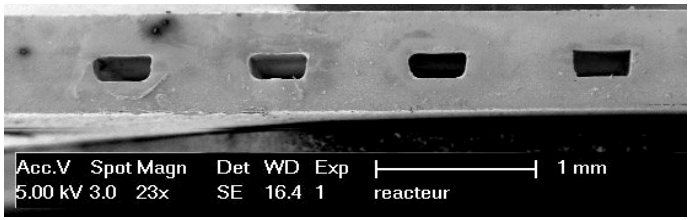


3. Meanders: microcalorimeter 4

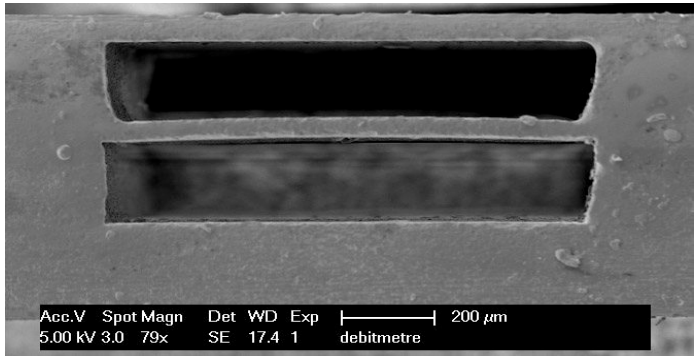


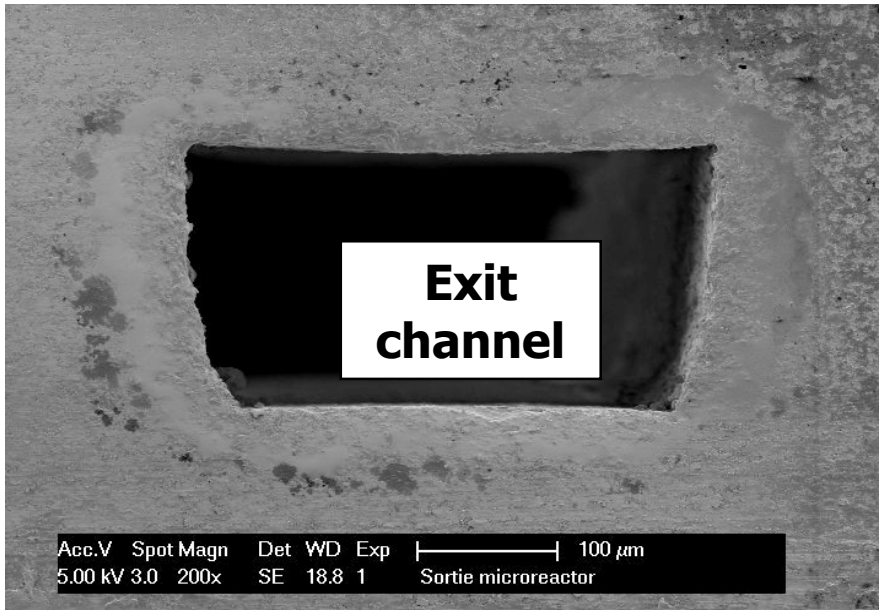
- Complete reactor
- LTCC: elements
- LTCC: fluidic layout
- LTCC: layers & lamination

Reaction zone



Flow meter





3. Fluidics: lamination quality

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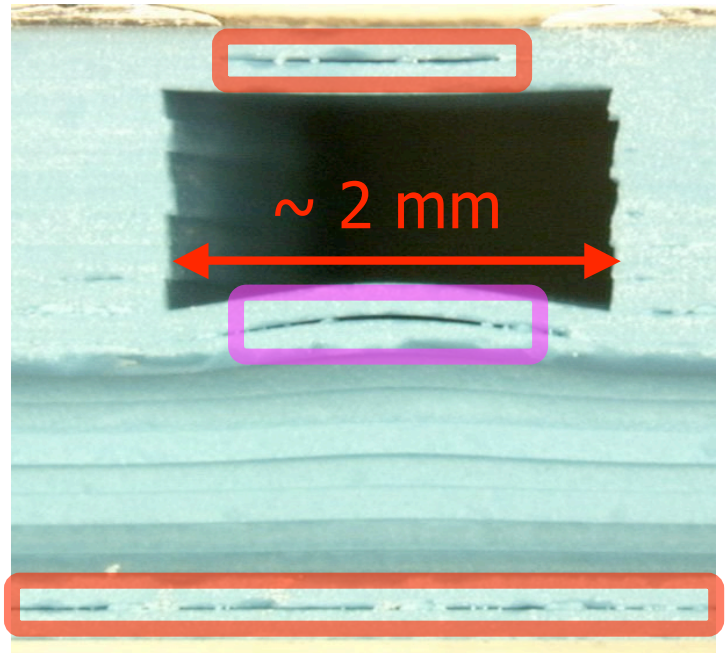
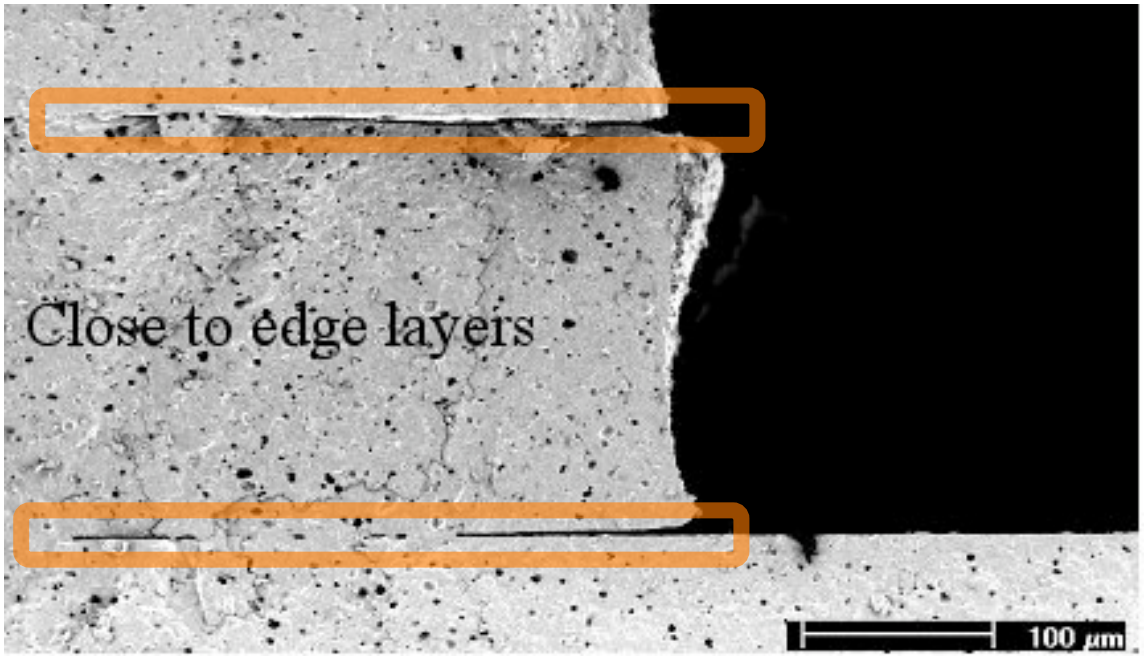
Zones with reduced lamination pressure:

→ **low-pressure lamination!**

- Above & below channels
- Crossings
- Edges





3. Cutting & stacking - conclusions

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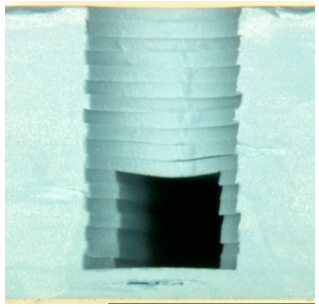
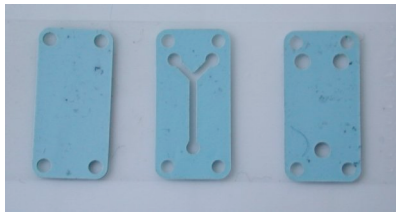
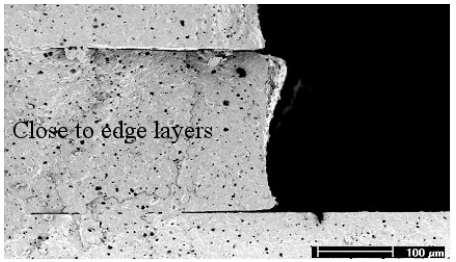
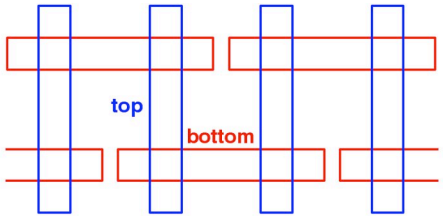
+ Very simple technique
+ Straightforward processing
+ Can achieve large channels



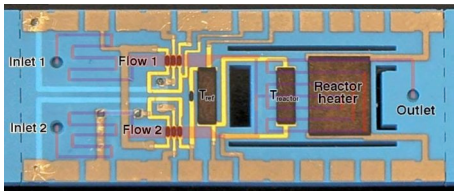


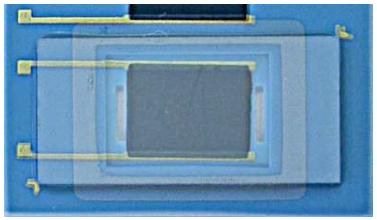


– Quality problems with large channels w/o inserts
– Alignment tolerances → small dead zones



→ Microreactors
→ Suspended heaters (gas sensors)
→ Structured cantilevers





4. Carbon sacrificial layers - process

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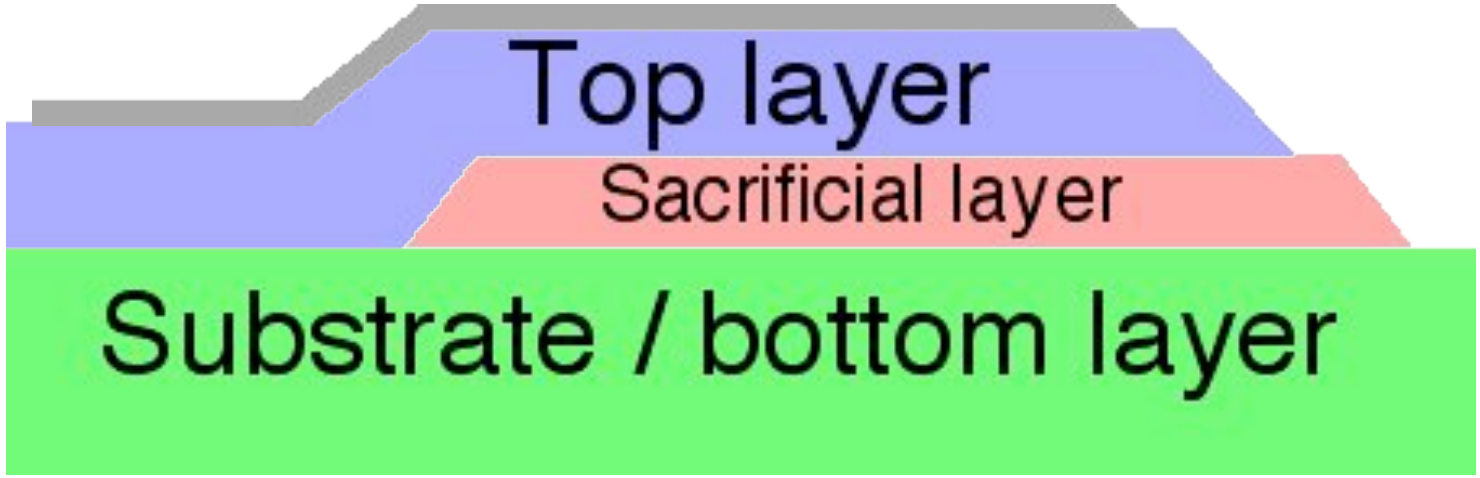
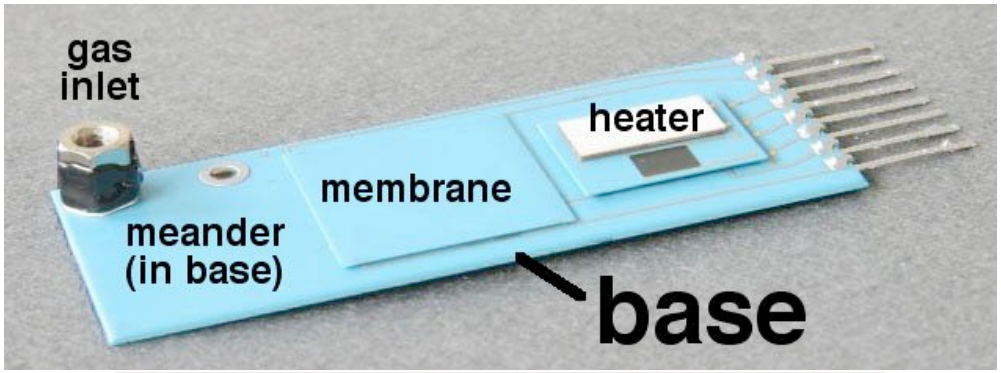
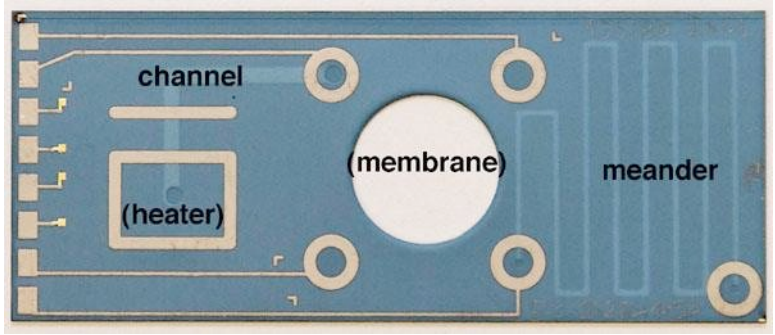
- Print [fire] sacrificial paste onto LTCC / ceramic substrate
- Laminate (LTCC) / print (ceramic) top layer
- Fire structure in air / O_2, OR:
- Fire structure in neutral gas & oxidise later
- Post-processing

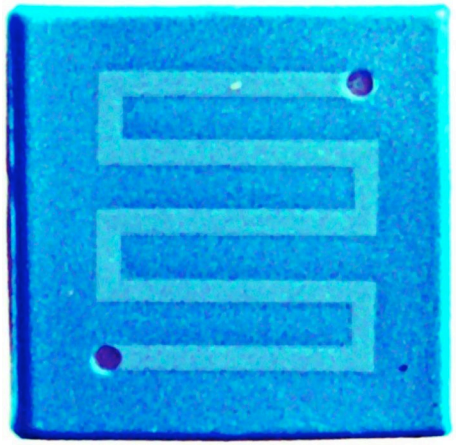


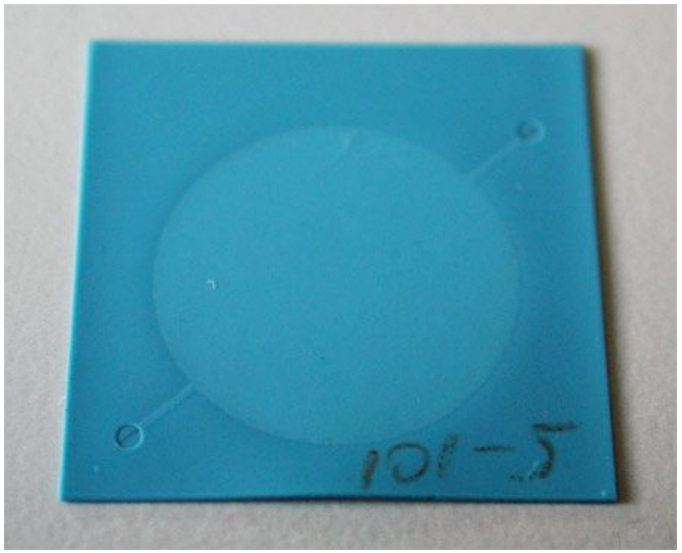
4. Carbon layers - applications

- Fluidic resistors
- Membranes
- Gas viscosity sensor
- Carbon: membrane & meander









4. Carbon layers - membrane issues

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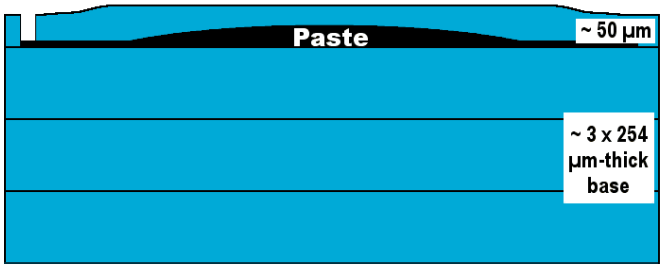
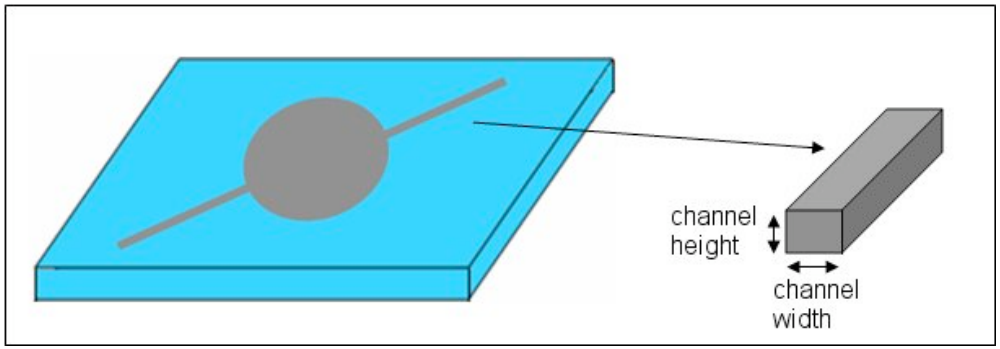
- LTCC membrane: 3x support + 1 thin (50 µm) DP 951 tapes
- Channel width (2:1) & height (2:1)

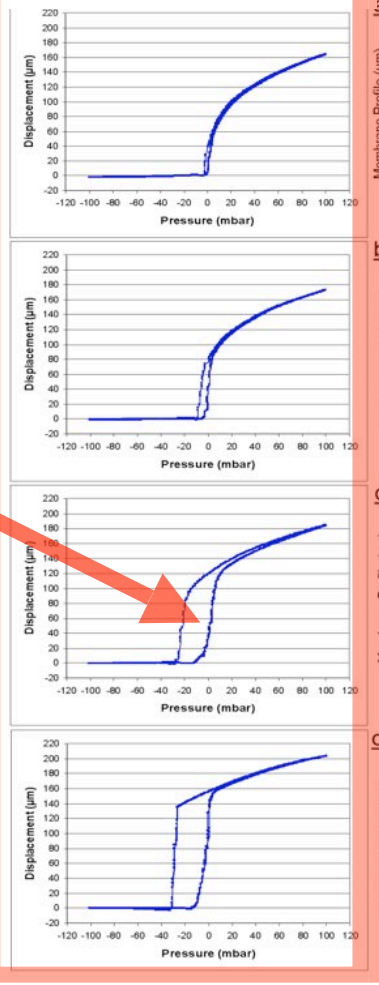
→ **Strong change of properties**



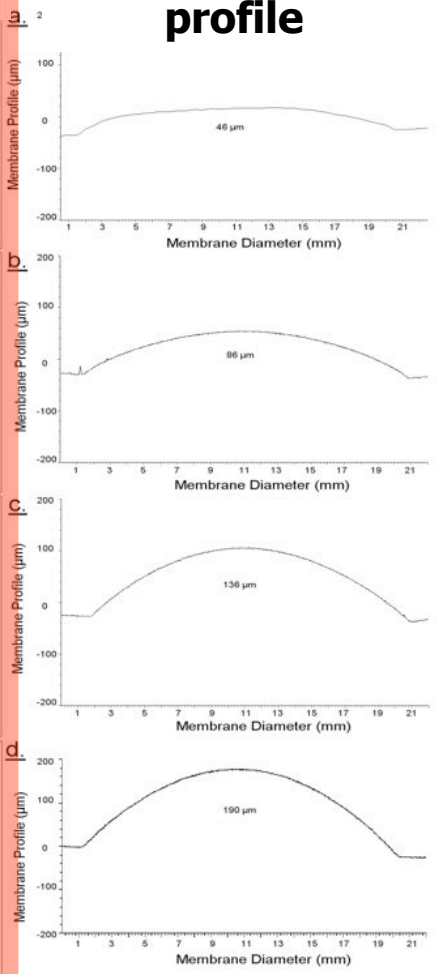


Hysteresis

Pressure-displacement



Membrane profile



4. Sacrificial carbon - conclusions

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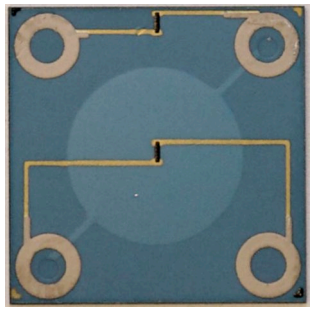
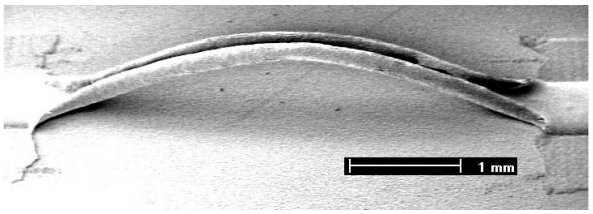
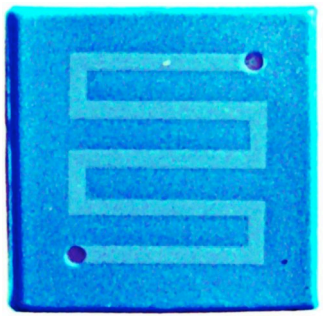
+ Simple processing
+ No lamination problems
+ Thin & large membranes achieved



– Very process sensitive for membranes
– LTCC: swelling, sagging
– Thick film: sagging, lateral shrinkage, curling
– Limited thickness compared to cutting



→ Microfluidics, fluidic "resistors"
→ Membranes



5. Mineral sacrificial layers - process

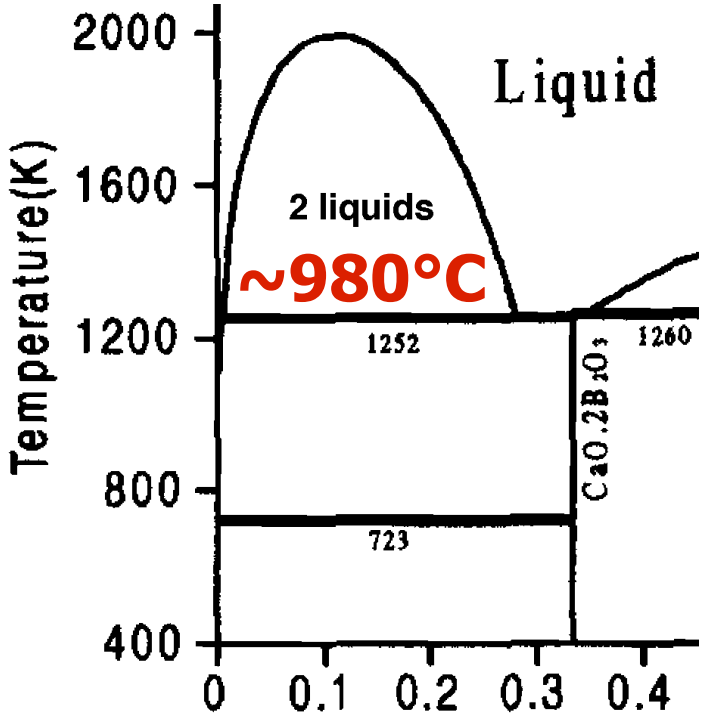
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

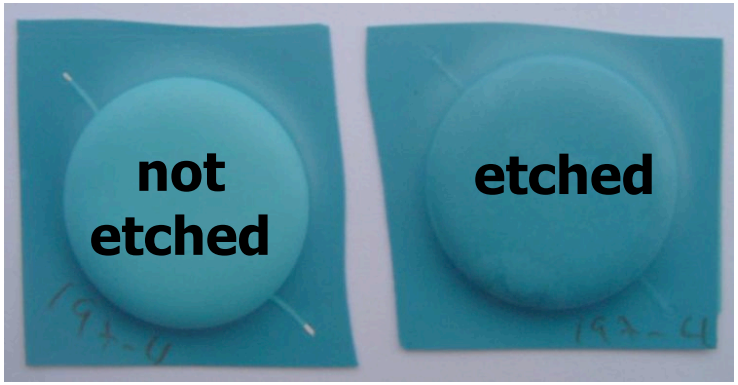
- Print [fire] sacrificial paste onto LTCC / ceramic substrate
- Laminate (LTCC) / print (ceramic) top layer
- Fire structure
- Chemically etch sacrificial layer

→ Requires relatively "open" structure

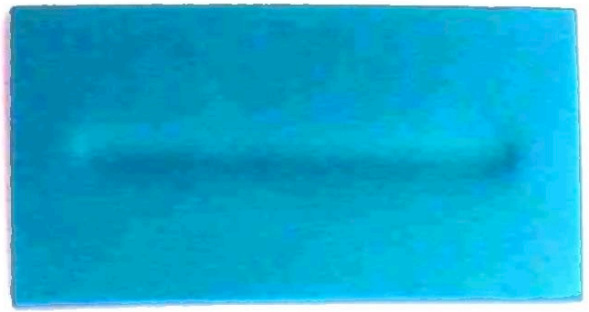
5. Mineral layers - $CaO + B_2O_3$

- For dissolution in acids: basic system
- Filler: CaO or $CaCO_3$
- Glass: B_2O_3 or borax ($Na_2B_4O_7$)
- **$CaO - B_2O_3$** : low shrinkage (ca. 8%)
- Sintering hindered by CaO-B_2O_3 reaction?
- Deformed LTCC
- Very good dissolution in acids





Sintered LTCC + paste



5. Mineral layers - CaO + borax

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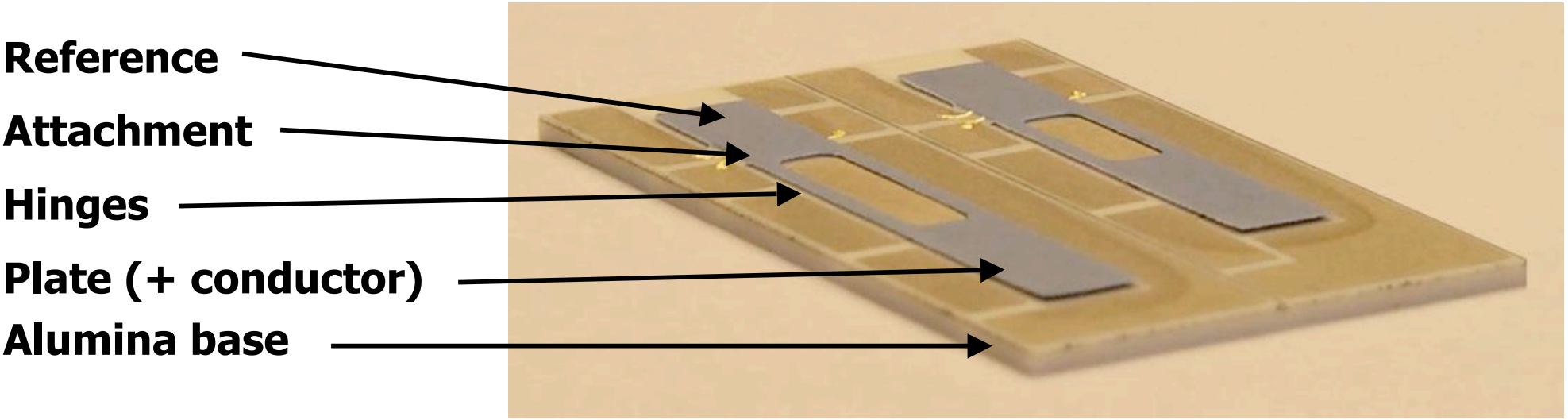
- B_2O_3 replaced by borax ($Na_2B_4O_7$)
  - Reduced B_2O_3 volatility
  - Melting at ~740°C
- Dense & good cohesion with enough borax

→ **Capacitive force sensor** (thick-film dielectric + conductor)



5. Mineral layers - issues

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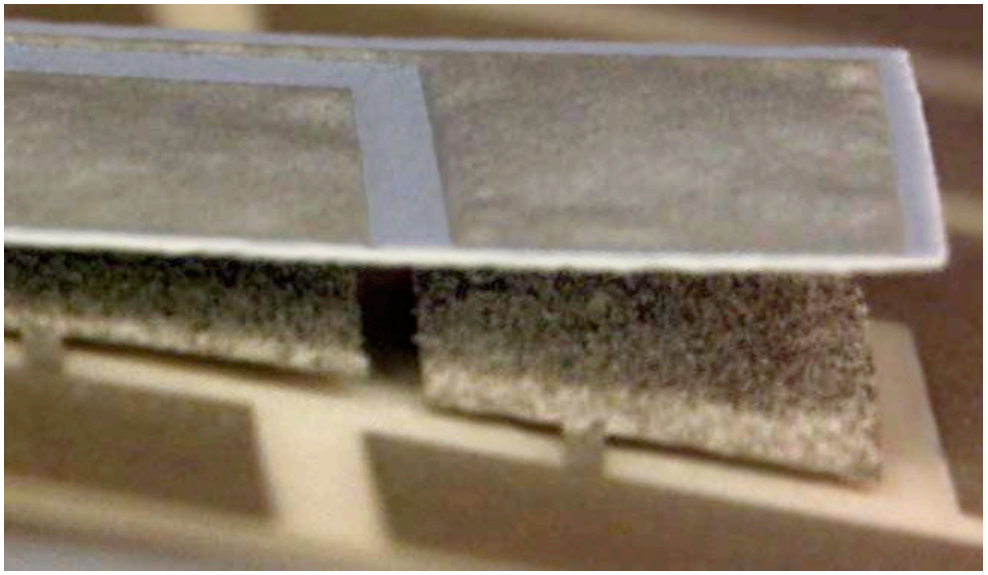
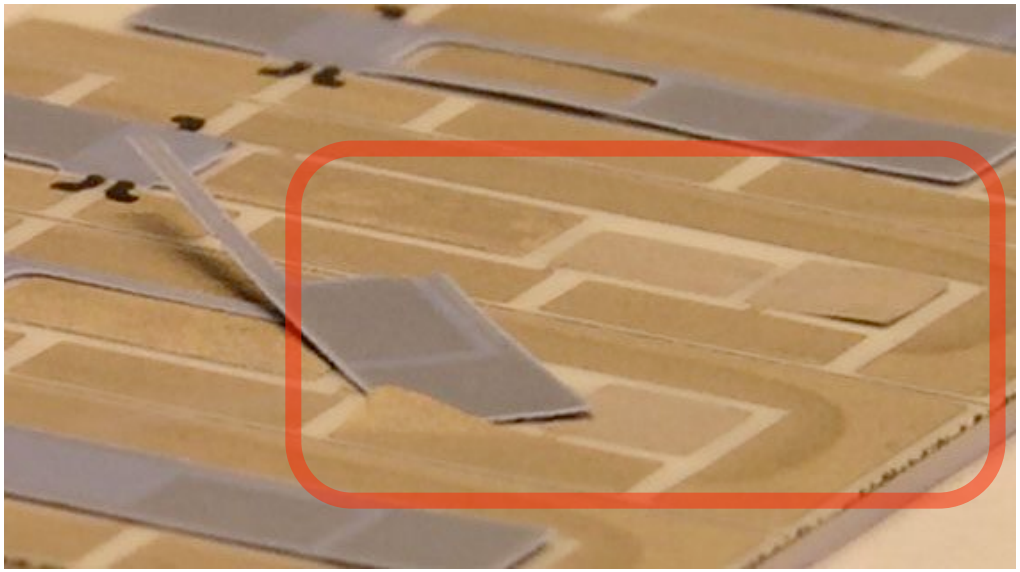
- Strong reaction with LTCC & thick films (Na)
- Difficult to remove by etching
- Peeling of conductor under sacrificial paste upon etching (Na)

→ **Only small amounts of alkali oxides allowable**





5. Mineral layers - conclusions

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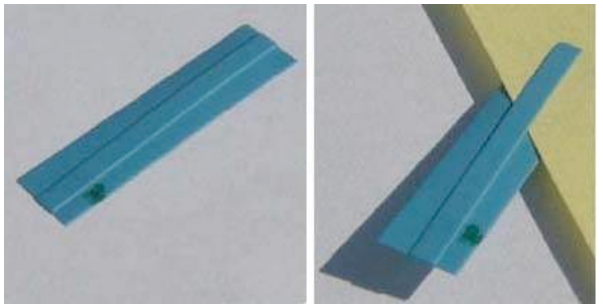
+ Universal: LTCC, thick-film, glass, …
+ Straightforward processing
+ No lamination problems
+ No sagging / swelling during firing



– Need etching + cleaning steps
– Reactions with other layers
– Shrinkage matching needed on LTCC

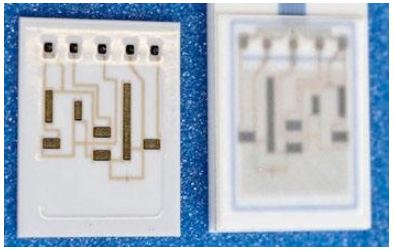
→ Open structures: cantilevers, bridges,…
→ **Work in progress !**

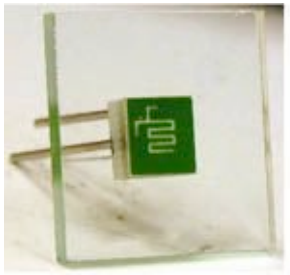
6. Conclusions

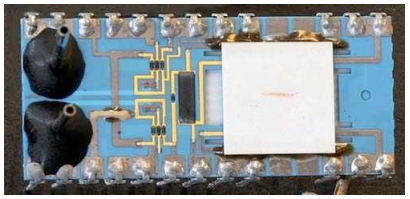
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

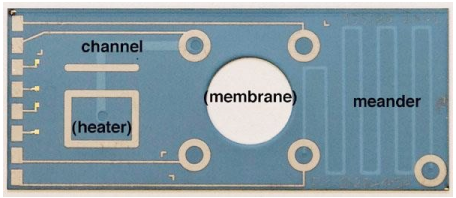
Wide range of methods available:

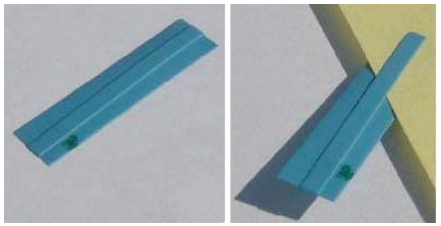
- **Glass sealing (+ dielectric)**
  - Hermetic sealing
  - Simple fluidics (1 layer)
- **Cutting & stacking**
  - Fluidics (large); reactors
  - Structured mechanical sensors
- **Carbon- & mineral-based sacrificial layers**
  - Complex fluidics
  - Micromechanical structures











Merci

ÉCOLE POLYTECHNIQUE
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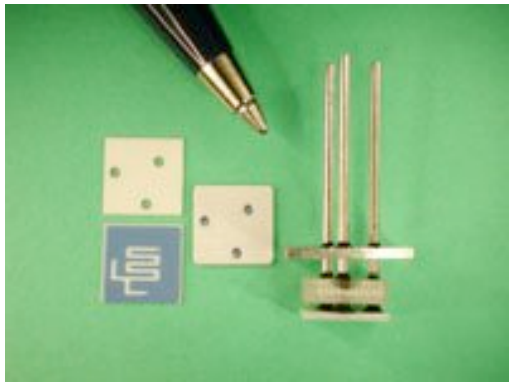

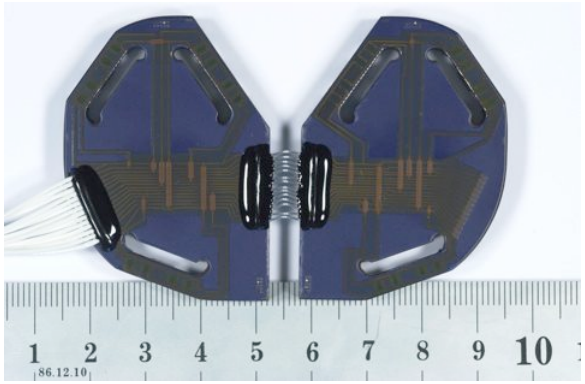

Thank you !